SUMMARY OF EXPERIENCE WITH

SHORT-DURATION LOW FREQUENCY

CHAMBER PRESSURE OSCILLATION ON LM ASCENT

ENGINE

REPORT NO. 8258-927045

DECEMBER 4, 1967

BELL AEROSYSTEMS - A textron COMPANY

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BACKGROUND

In a large number of test runs with the LM Ascent Engine, short periods of low frequency oscillations have been noted. These discrete periods generally occur very early during the run; in many cases before effective steady state operation is achieved. The oscillation frequency is about 400 cps and the duration of the disturbance is less than 1 second, generally averaging about 200 milliseconds. Because of the characteristic shape of the oscillation traces; i.e., a gradual buildup and decay of the oscillations, the name "football" has been attached to the phenomenon. Figure 1 shows an example of such a "football." It may be noted that only minor corresponding indications are perceptible on the accelerometer traces.

An experimental and analytical investigation was undertaken to establish a model to explain the cause of these short-duration oscillations. The analytical investigations were greatly furthered by the efforts of Messrs. D. Drain, R. Darsh and Associates at the Lewis Research Center of the N.A.S.A.

The principal experimental investigations relating to "footballs" were conducted with injector E2B-S/N 12 in vertical sea-level test facility 2DW. This feed system closely simulates the actual LM configuration. It has approximately the same feed line length, volume and configuration. The test series, conducted at Bell Test Center, was comprised of runs 2DW-111 through 2DW-187. On the basis of these tests, the following observations can be made:

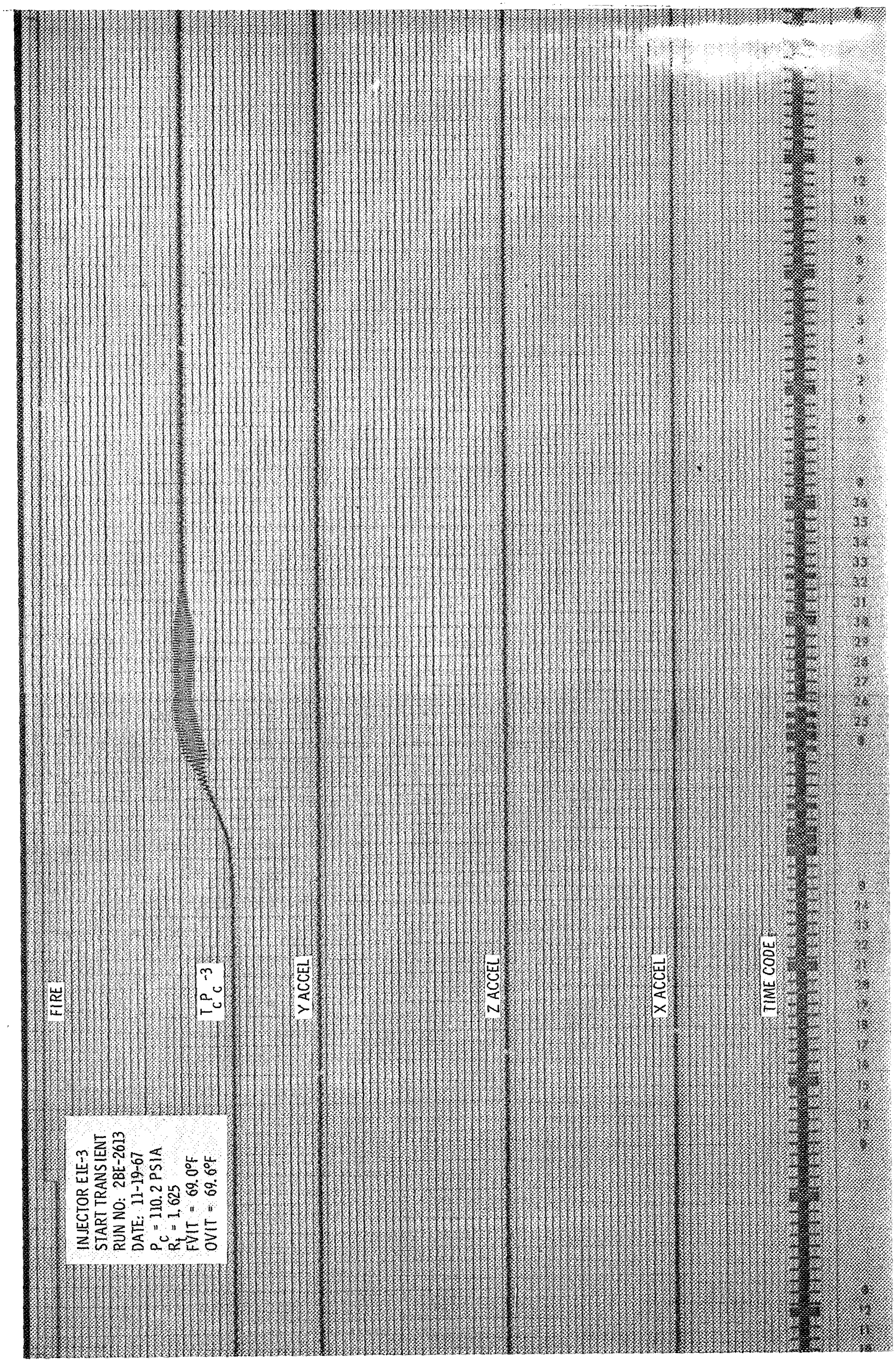

INJECTOR E1E-3
START TRANSIENT
RUN NO: 2BE-2613
DATE: 11-19-67
P_c = 110.2 PSIA
R_t = 1.625
FVIT = 69.0°F
OVIT = 69.6°F
FIRE
$T_c P_c$ -3
Y ACCEL
Z ACCEL
X ACCEL
TIME CODE

Figure 1

1. The fuel system is the controlling component in initiating "footballs."

Helium gas injected into the fuel system establishes and maintains a "football" of the same frequency as a self-induced one. The oscillation stops with the cessation of gas introduction. Injection of gas into the oxidizer system did not produce any low frequency oscillations.

2. The rated "football" incidence, magnitude and time of duration decrease as the chamber pressure (with a given thrust chamber assembly) or the fuel pressure drop increase. However even high pressure drop, corresponding to a $P_c = 135$ psia, does not eliminate "footballs" if a two-phase mixture flows through the fuel feed system. Helium injected into the fuel system maintained "footballs" irrespective of the chamber pressure investigated.

3. High propellant gas saturation increases the incidence rate, magnitude and duration of "footballs." However even with the highest gas saturation levels obtainable in the fuel, 0.0053% (weight) of helium, which is larger by a factor of 3 than the highest saturation values given in the literature, the "football" duration was always less than 1 second.

These observations are consistent with the following analytical model:

The injector resistance (or pressure drop) portions of the injector feed impedances are not large enough to stabilize the injector feed system-combustion chamber interaction of the engine without the dynamic assistance of at least one side of the bipropellant system. At normal operating conditions, the oxidizer side of the injector feed system (oxidizer manifold and orifices) appears to have more fluid compliance (or less stiffness) than is present in the fuel system (injector manifold and orifices).

Furthermore, the engine is relatively insensitive to increases in oxidizer compliance as indicated by the lack of response to helium injection on the oxidizer side. During steady state operation, the fuel side compliance is low enough so that the stiffness of the injector fuel side can provide sufficient amount of additional stabilization to that provided by the injector resistances to prevent oscillations. This is analogous to an electrical RC circuit. Therefore, the stability of the engine is sensitive to changes in fuel-side-feed system compliance. This is demonstrated by the fact that injection of helium gas into the fuel feed system caused "footballs." Feed-line resonance does not appear to be a significant factor since the frequency of oscillation is substantially the same irrespective of the feed line length and hydraulic characteristics among different cells. It appears that the 400 cps frequency is determined primarily by combustion chamber time constants rather than by feed system resonances. The observations also indicate the very important fact that the sum of the resistance and compliance reactance is sufficient under normal operation including high gas saturation conditions to stabilize the engine; it is only when two-phase conditions, such as during start transients when gas comes out of solution or inhomogeneities due to gas traps, are encountered that the engine system will oscillate at the 400 cps frequency.

In the analysis of the "football" data gathered during testing with E2C injectors, a word of clarification is required. In evaluating "football" incidences, all oscillations subsequent to the initial chamber pressure overshoot during start transient have been counted even though the effective steady state has obviously not been reached at this point. The specification (para. 6.2.39) defines effective steady state operation as periods of constant thrust, 0.100 seconds after the rate of change of the mean chamber pressure has become less than 10% per second of the full thrust chamber pressure and during the period when the rate of change of the mean chamber pressure remains less than 10% per second of the full thrust chamber pressure.

ANALYSIS OF E2C "FOOTBALL" DATA

The majority of the "football" data have been collected as a by-product of the bomb stability testing. As will be seen later, this type of operation, where the run rate is very high and constant propellant temperature is maintained by conditioning it in a recirculating system, represents an extreme situation as far as "football" magnitude, duration and incidence are concerned. This is explainable by the fact that the continuous repressurization and the technique used of bringing the propellant in on top of the tank and letting it settle through the pressurizing gas during conditioning promotes a high degree of saturation. This is confirmed by the fuel saturation data collected from test cell 2DW and shown in Figure 2. This indicates that the fuel has been continuously saturated over this extended period of time.

The "football" data will first be discussed in terms of the pertinent parameters: Oscillation Frequency, Time of Occurrence, Duration, Amplitude and Rate of Incidence. Following this discussion the relationship and interaction of "footballs" with detonations and high frequency instability will be evaluated.

A. Frequency of Oscillations

In Figure 3, the frequency of oscillations are plotted as a function of chamber pressure for the various indicated injectors. Injector S/N 44 is an E2B type and can be used as a comparison of the E2C with the E2B. The frequencies represent average values counted during the short periods of oscillations; thus some scatter due to analysis techniques can be expected. However, it can be seen that the mean of the oscillation frequencies, similar to the E2B's, is about 400 cps. There is also some indication that the

Date	Sample No.	Sampling Pressure (psia)	Sampling Temperature (°F)	$C_{H_C} \times 10^3$ (wt + %)	$\frac{C_{He} \text{ Measured}}{C_{He} \text{ Saturation}}$
9/28/67	A-88	112	78	NiC	
9/30/67	A-89	115	75	0.6	0.9
10/1	A-90	110	79	0.4	0.6
10/2	A-91	112	70	0.9	1.5
10/5	A-94	Questionable →		0.6	?
10/6	A-95	112	41	0.47	1.2
10/7	A-96	95	40	0.34	1.0
10/11	A-98	100	63	0.77	2.0
10/13	A-99	Questionable →		0.88	?
10/13	A-100	Questionable →		0.82	?
10/14	A-101	110	75	0.81	1.3
10/15	A-103	120	71	(2.24)	(3.6)
10/17	A-104	105	76	1.10	1.8
10/18	A-105	100	76	0.86	1.5
10/19	A-106	110	76	1.15	1.9
10/20	A-107	105	42	0.68	1.8
10/21	A-108	115	82	0.84	1.3
10/24	A-111	100	75	0.75	1.3
11/13	A-131	110	85	0.61	0.9
11/14	A-132	105	60	0.68	1.2
11/14	A-133	Questionable →		0.61	?
11/15	A-134	105	70	0.49	0.9
11/16	A-135	105	73	0.50	0.9
11/17	A-136	95	40	0.27	0.8
11/17	A-138	115	85	0.78	1.1
11/18	A-139	115	120	1.00	0.95

Figure 2. Helium Concentration Analysis of Fuel

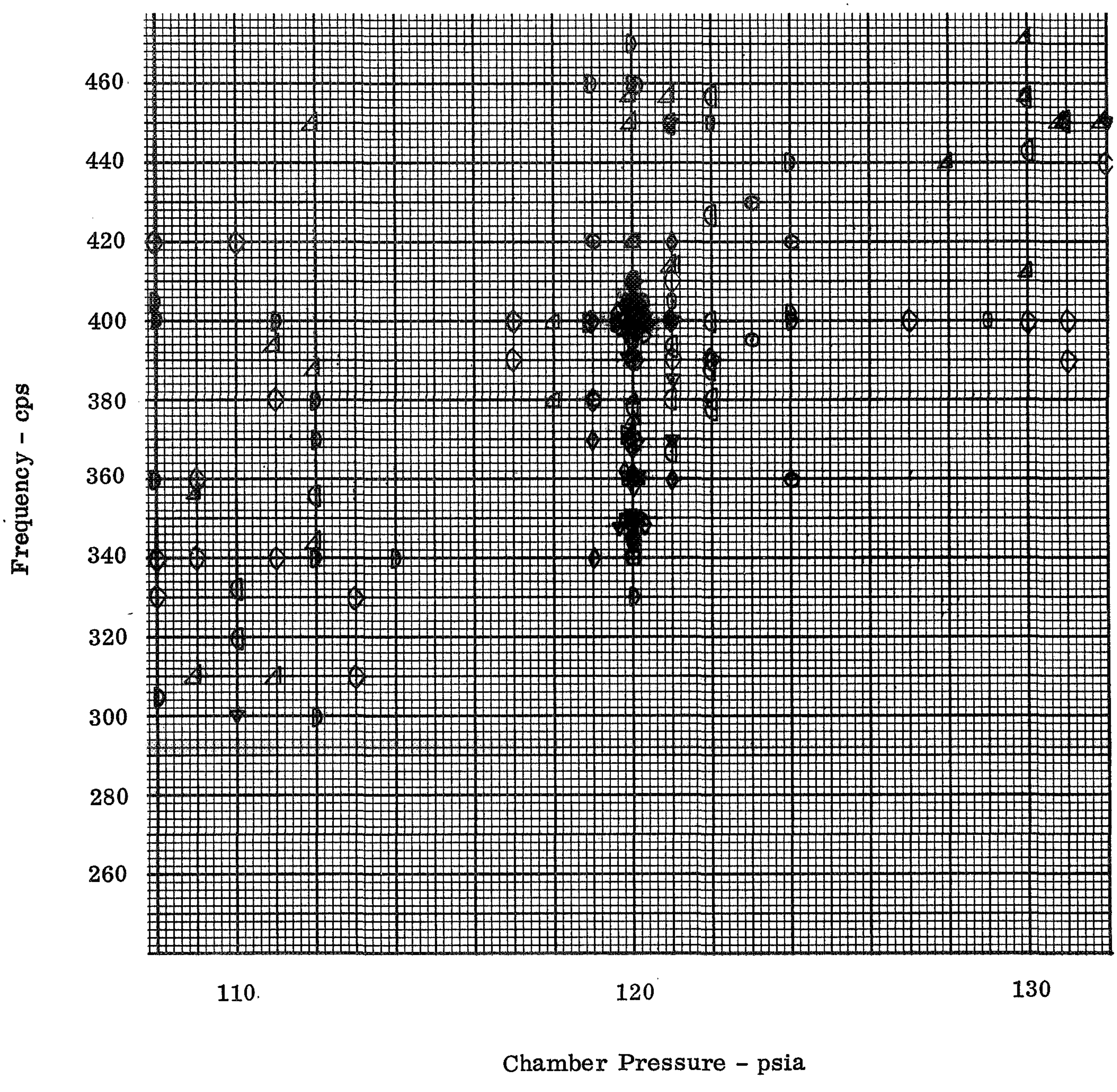


Figure 3. Frequency versus Chamber Pressure

frequency increases somewhat with chamber pressure. This is to be expected since higher pressure drop causes higher orifice flow velocity and therefore a higher frequency.

B. Time of "Football" Incidence

The time of "football" incidence is a function of the propellant feed system. In the horizontal test facilities 2BE, 3DE and 1BN, which have long lines, multiple "footballs" have been observed during a given run. Although this will be discussed further in the next section, it does appear that these horizontal, non-flight type system cells have characteristic incidence times which correspond to locations of poor bleeds. For example, in cell 1BN, in the first test ("A" start) of a series it is not uncommon to obtain a "football" at about 4 seconds into the run. In subsequent tests, the so-called "B" starts, the incidence rate is very low. It has, for example, been shown that whenever new flow meters are installed, the subsequent run is prone towards "footballs." In order to relate the incidence time to the LM feed system, these have been plotted in Figure 4 for cell 2DW, the vertical test stand with the simulated LM feed system. No multiple "football" has ever been observed in this cell, probably because the lines are short and do not provide much opportunity for gas traps. It may be noted that the "footballs" commence on the average about 15 milliseconds after chamber pressure overshoot. This is consistent with the data obtained with E2B's.

C. "Football" Duration

As stated in the previous section, although multiple discrete "footballs" per run have never been noted in the vertical facility 2DW, they have occurred in the horizontal facilities with non-flight type feed system configuration

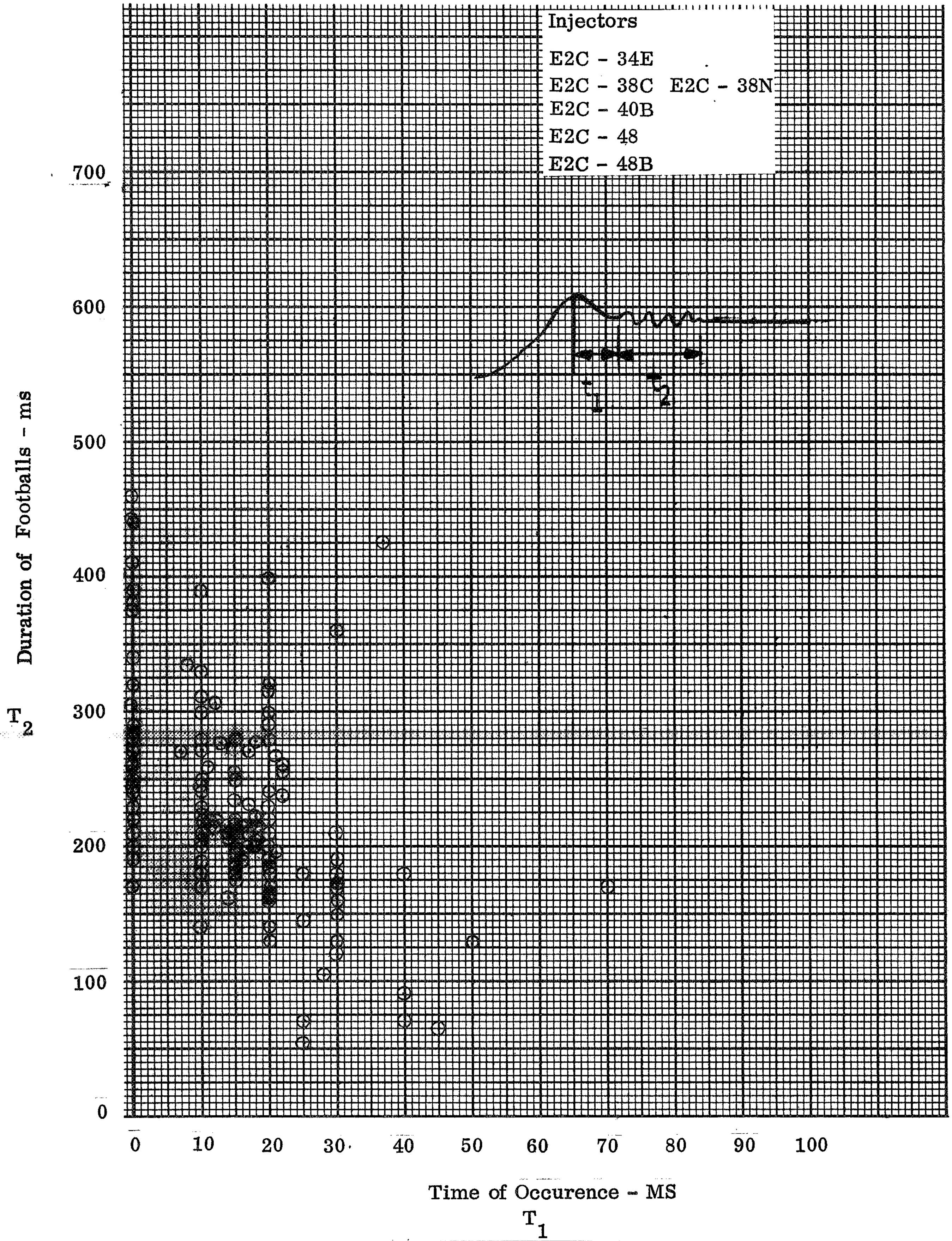


Figure 4. Time of Occurence versus Duration of Football Cell - 2DW

In Figure 5, a listing is shown of the various runs with indication of discrete multiple "football" incidences. It may be noted that in these facilities multiple "footballs" have been rather common. There have been occasional tests in these horizontal cells where a multiple "football" was formed subsequent to bomb detonation. This occurs primarily at low chamber pressure operation and it is not too surprising since subsequent to the bomb detonation the chamber pressure decays significantly for about 5 milliseconds, and thus the pressure levels reach magnitudes similar to those encountered during start transients. Figure 6 is a listing of the tests in which "footballs" were noted subsequent to the bomb detonation. The frequency, duration, and magnitude of these "footballs" are similar to those encountered earlier in the test.

In Figure 7 (a) the duration of each discrete "football" has been plotted versus chamber pressure for a typical set of tests. It may be noted that the period of oscillation decreases with chamber pressure. The average single "football" duration at nominal operating conditions is about 200-300 milliseconds. In Figure 7 b the <u>total</u> durations of <u>all</u> multiple "footballs" per given run have been plotted. This indicates that even with multiple "footballs" the <u>total</u> periods of oscillations do rarely exceed 1 second.

The important conclusion to be derived from these data is the observation that the "football" durations are finite, lasting no longer than a few hundred milliseconds.

D. <u>"Football" Amplitude</u>

In Figure 8 the peak-to-peak amplitudes of the "footballs" are plotted for various injectors as a function of chamber pressure. Although there is some random scatter, the average peak-to-peak amplitude appears to be about 70 psi. The "football" amplitude in the vertical facility 2DW appears to be

Inj S/N	Test No.	Test Cell	No. of Footballs	P_c Level	Football Durations 1	2	3
E2C-39B	2601	2BE	1	115	650		
	2602		2	117	170	380	
	2603		2	120	170	250	
	2604		2	121	140	220	
	2618		1	128	120		
	2619		2	130	80	60	
	2620		1	131	60		
	2621		1	130	60		
	2622		1	109	560		
	2623		1	-	740		
	2624		1	106	730		
	2625		1	107	740		
	2626		1	-	380		
	2627		2	-	680	250	
	2628		3	112	200	310	150
	2629		2	111	680	180	
	2630		2	-	1060	220	
	2631		3	120	180	130	50
	2632		3	121	150	140	80
	2633		N/A	120			
	2634		N/A	120			
	2635		1	131	30		
	2636		1	128	80		
	2637		1	131	30		
	2638		1	132	50		
E2C-47I	2539		2	122	140	120	
	2540		2	122	250	140	
	2541		2	122	150	130	
	2542		2	121	160	160	
	2543		1	131	110		
	2544		1	130	100		
	2545	2BE	1	130	120		

Inj S/N	Test No.	Test Cell	No. of Footballs	P_c Level	Football Durations 1	2	3
E2C-47I	2546	2BE	1	130	120		
	2547		1	110	690		
	2548		1	110	640		
	2549		1	112	610		
	2550	2BE	1	112	530		
	1218	3DE	1	-	460		
	1219		1	120	460		
	1220		1	120	430		
	1221		1	121	410		
	1222		1	122	440		
E2C-47J	1228	3DE	2	120	150	70	
	1229		2	119	180	180	
	1230		2	117	140	210	
	1234		2	111	510	210	
	1241		2	108	660	320	
	1242		2	108	480	320	
	1248		2	121	90	140	
	1250		2	122	130	170	
E2C-47K-1	1251		2	118	160	180	
	1252		2	120	180	240	
E2C-47K-2	1253		2	120	100	160	
E2C-47L	1256		2	120	160	140	
	1321		2	120	180	130	
	1323		2	120	180	250	
E2C-47	1160		2	122	70	150	
	1164		2	120	160	190	
E2C-47A	1165		2	123	150	220	
	1166		2	124	250	280	
	1167	3DE	2	119	170	260	
E2C-47C	777	3DW	2	120	120	190	

Figure 5. Multiple "Football" Incidence per Cell

Inj S/N	Test No.	Test Cell	No. of Footballs	P_c Level	Football Durations 1	2	3
E2C-	1180	3DE	3	120	200	260	140
47D	1184	↕	2	120	150	240	
	1185	3DE	2	120	140	330	
E2C-	2463	2BE	2	120	220	200	
47E	2464	↑	2	120	170	260	
	2466		2	120	170	290	
	2467		2	120	310	160	
	2468		2	120	270	160	
	2469		2	120	170	480	
	2470		3	120	160	130	150
	2471		2	120	170	170	
	2472		2	120	190	160	
	2473		2	120	310	140	
	2474		2	120	170	170	
	2475		2	120	310	160	
E2C-	2479		3	120	170	260	150
47F	2480		2	121	170	210	
	2481		2	121	170	140	
E2C-	2483		2		180	230	
47G	2484		2		170	130	
	2485		2		170	180	
	2486						
	2487		2		180	240	
	2489						
	2490						
E2B-	2332		1	120	180		
44	2334		1	110	260		
	2335	↓	2	120	200	120	
	2336	2BE	1	110	140		
	704	3DW	1	120	230		
	705	↕	1	120	180		
	707	3DW	1	120	200		

Inj S/N	Test No.	Test Cell	No. of Footballs	P_c Level	Football Durations 1	2	3
E2B-	2387	2BE	1	120	170		
44	2388	↑	1	120	220		
	2389		1	120	190		
	2390		1	120	240		
	2391	↓	1	120	250		
E2C-	2492	2BE	1	134	60		
47G	2493	↑	1	134	80		
	2494		1	111	1*		
	2496		1	114	1*		
	2500		2	112	800	250	
	2501		2	112	1190	240	
	2502		2	108	1080	220	
	2503		1	120	**		
	2504		2	-	190	210	
	2506		3	124	180	220	160
	2507		2	120	170	170	
	2508		2	108	1170	190	
	2509		2	120	200	170	
	2513		2	119	150	240	
	2516	↓	2	120	170	160	
	2517	2BE	1	-	151		
E2C-	627	2DW	1	130	114		
40B	628	↑	1	120	232		
	629		1	122	254		
	630		1	121	255		
	633		1	120	257		
	634		1	120	296		
	635		1	120	270		
	636		1	121	259		
	637		1	121	306		
	638		1	121	222		
	639		1	120	315		
	640	↓	1	121	267		
	641	2DW	1	121	278		

*1-sec test - continued through bomb
**Spike at 0.7 sec - continuous through spike

Figure 5. Multiple "Football" Incidence per Cell (Cont)

INJECTOR	TEST CELL	TEST NO.	DURATION OF TEST	P_C LEVEL PSIA	BOMB PORT	FOOTBALL	
						FREQ.	AMP
E2C47H	2BE	2529	3.0	110	D	380	56
E2C47I	2BE	2541	3.0	120	D	390	22
E2C47J	3DE	1232	3.0	110	B	370	66
E2C47K	3DE	1252	3.0	120	B	400	33
E2C47K	3DE	1253	3.0	120	D	390	50
E2C48B	3DE	1268	3.0	110	L	400	33*
E2C48B	3DE	1269	3.0	110	B	390	46*
E2C34C	3DE	1280	3.0	110	B	370	57
E2C34C	3DE	1281	3.0	110	B	390	74
E2C34C	3DE	1287	2.2	110	B	370	55
E2C34C	3DE	1288	2.2	110	B	380	61
E2C34C	3DE	1289	2.2	110	B	380	81
E2C34D	3DE	1313	1	130	B	370	34*
E2C34D	3DE	1314	1	130	L	390	45*

* DENOTES - FOOTBALL OBSERVED IN CHAMBER STATHAM; NOT IN KISTLER CHAMBER GAGES. ALL PRESSURIZATION WITH NITROGEN GAS

Figure 6. Footballs Subsequent to Bomb Detonation

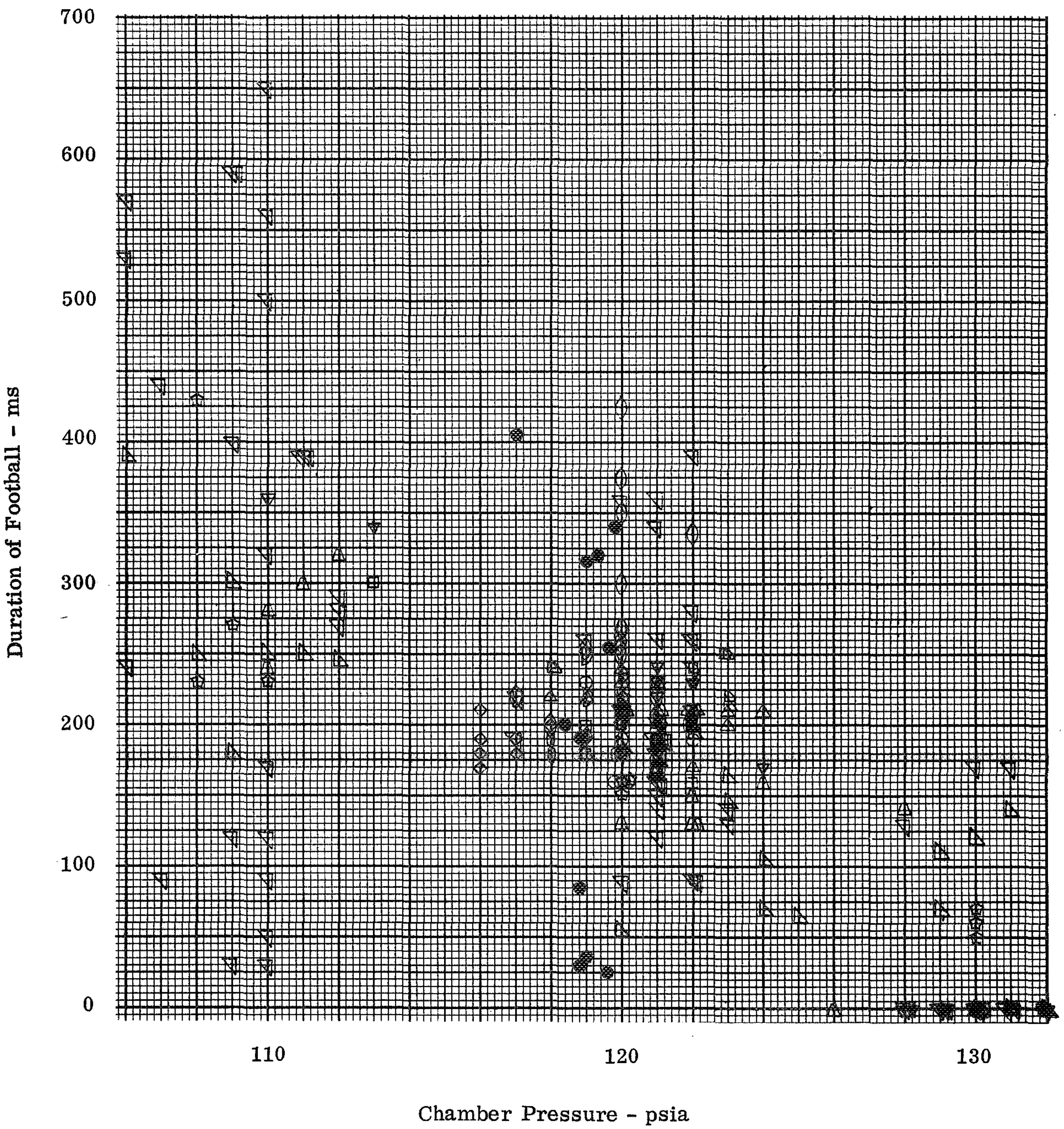


Figure 7a. Duration of Football versus Chamber Pressure

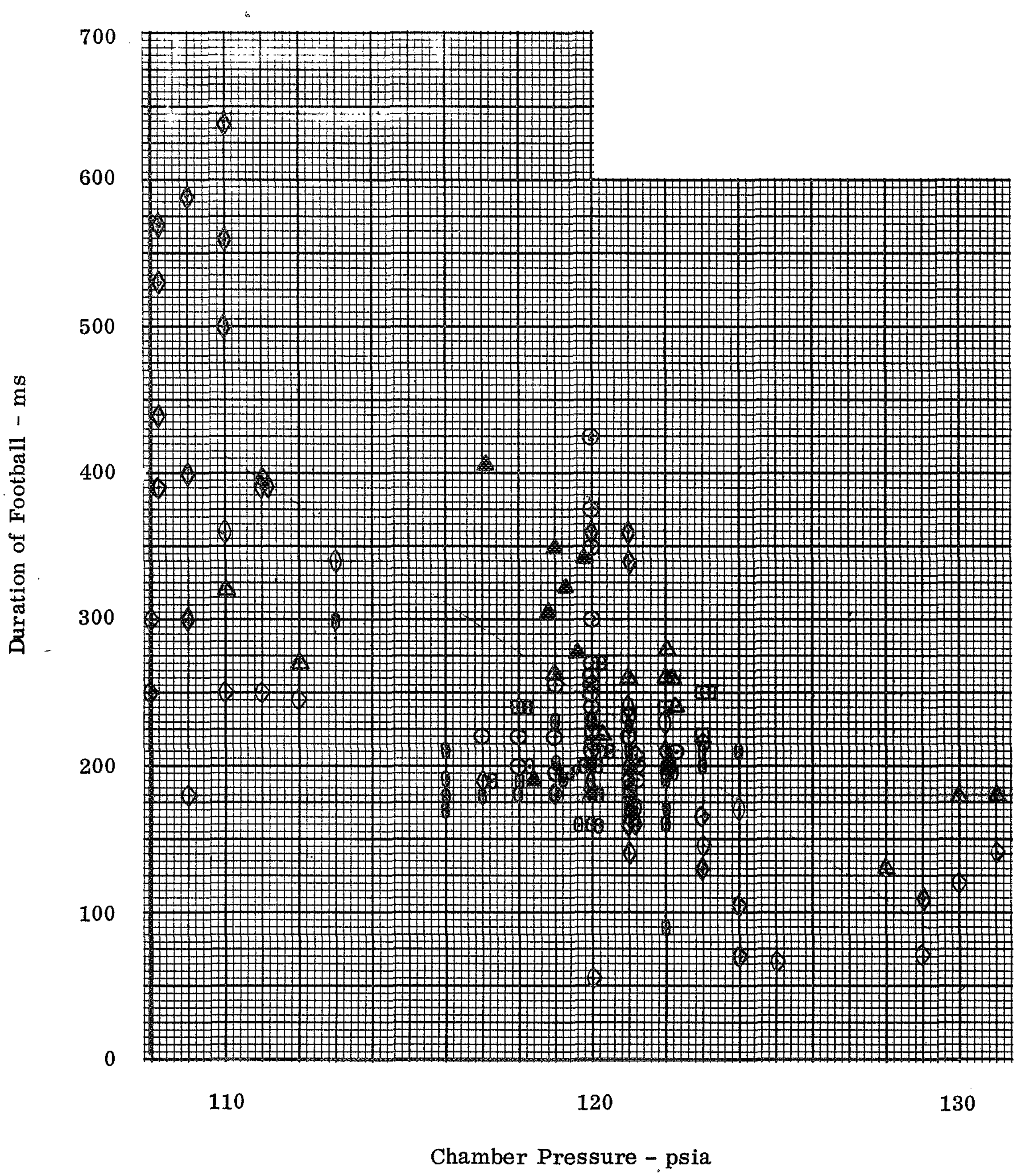


Figure 7b. Duration of Footballs versus Chamber Pressure

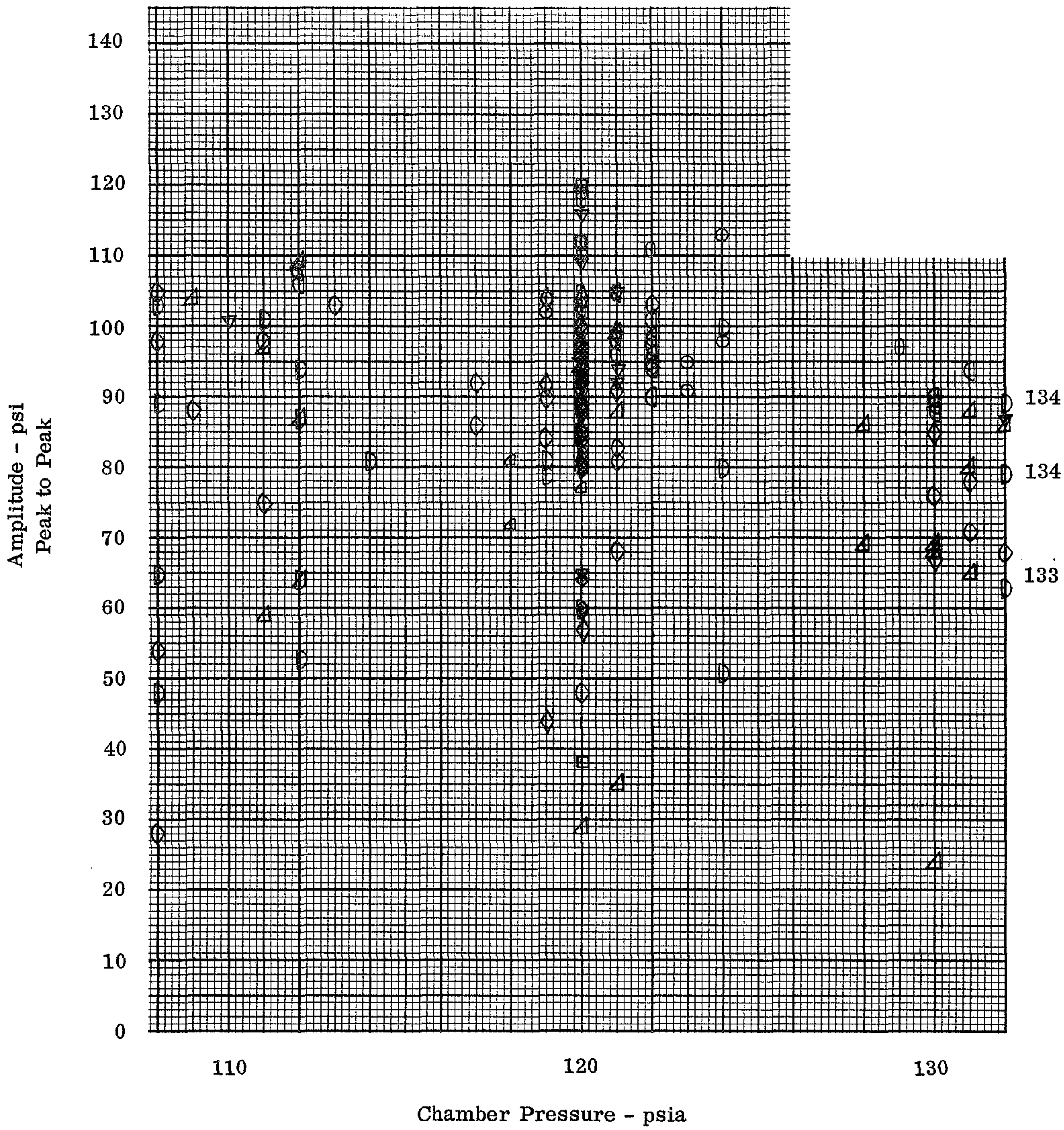


Figure 8. Amplitude versus Chamber Pressure

somewhat smaller than it is in the horizontal attitude cells. This is shown by the test data for the "P"-cooled injector S/N 40B, tested in the vertical test facility. The amplitude is only about 45 psi peak-to-peak. There is also the indication that the amplitude decreases as the chamber pressure increases.

E. Rate of Incidence

As has been noted several times, the rate of "football" incidence is highly dependent on the rate of testing, propellant gas saturation and specific test facility used. For example, in the altitude facility 1BN the occurrence of "footballs" is not as prevalent as it is in the sea-level facilities. For example, with injector S/N 8 only 3 "footballs" were noted in 13 tests. All three of these were at low chamber pressure. One reason for this might well be the fact that the temperature conditioning of propellants in this cell is through a different type of recirculating system, minimizing the degree of propellant saturation. In Figures 9 a to e, the incidence rate of "footballs" during bomb tests (i.e. high rate of testing) is plotted as a function of chamber pressure. It may be noted that the incidence rate drops sharply as a chamber pressure of 130 psi is reached. At the lower chamber pressures, however, a "football" is noted on almost every test.

Since the higher pressure drop gave indication of alleviating the occurrence of "footballs," E1E injector with a higher assembly pressure drop (40 psi vs 28 psi for the E2C) was built and tested. In the course of 18 tests to evaluate performance, only one small football was observed on a low chamber pressure test; however during bomb tests with injector E1B-1B, several "footballs" were observed, mostly again at the low P_c condition. The pertinent data are plotted in Figure 10 a to d. These tests confirm further the observation that higher

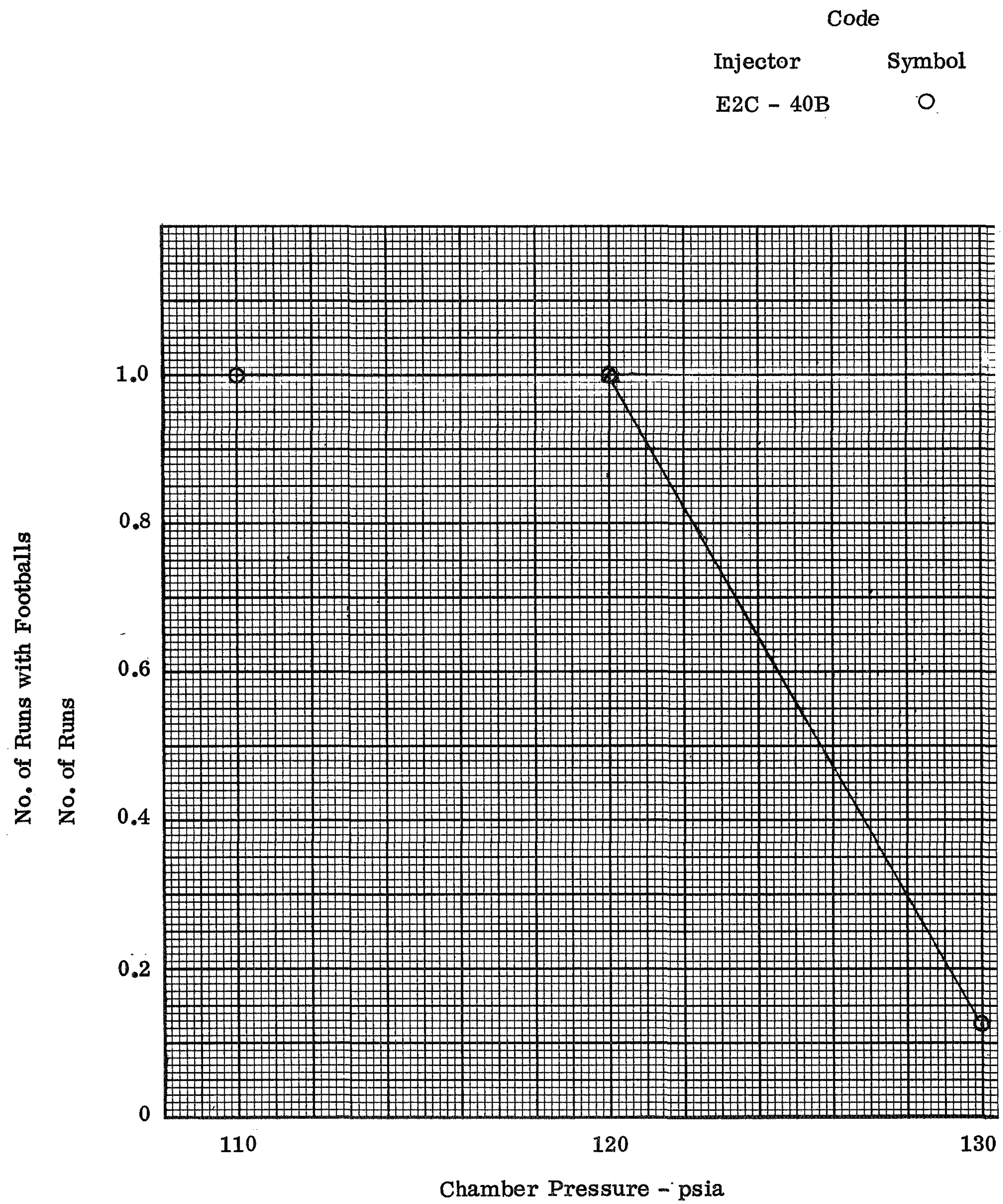


Figure 9a. Incidence of Runs with Footballs versus Chamber Pressure

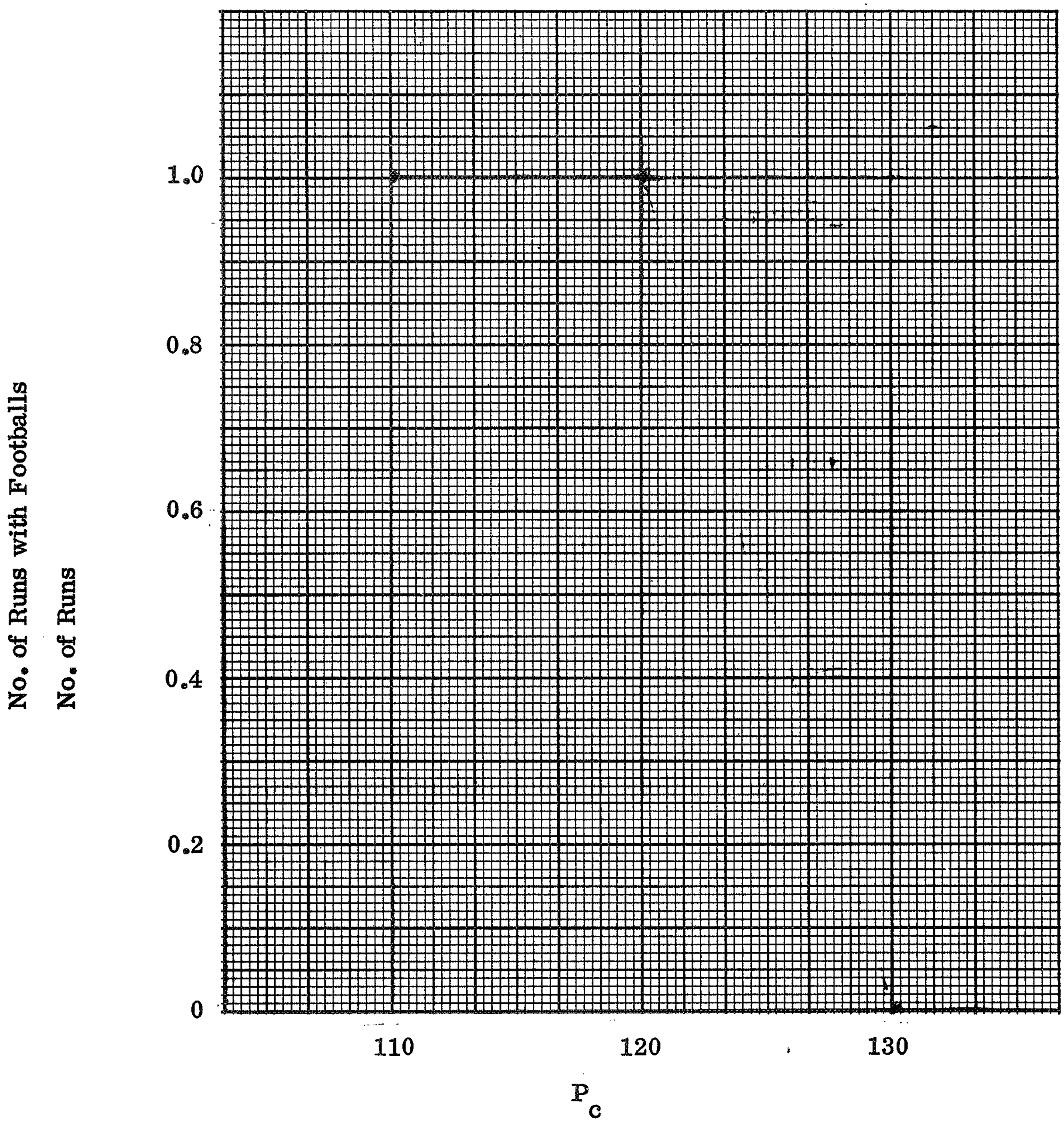


Figure 9b. Incidence of Runs with Footballs versus Chamber Pressure

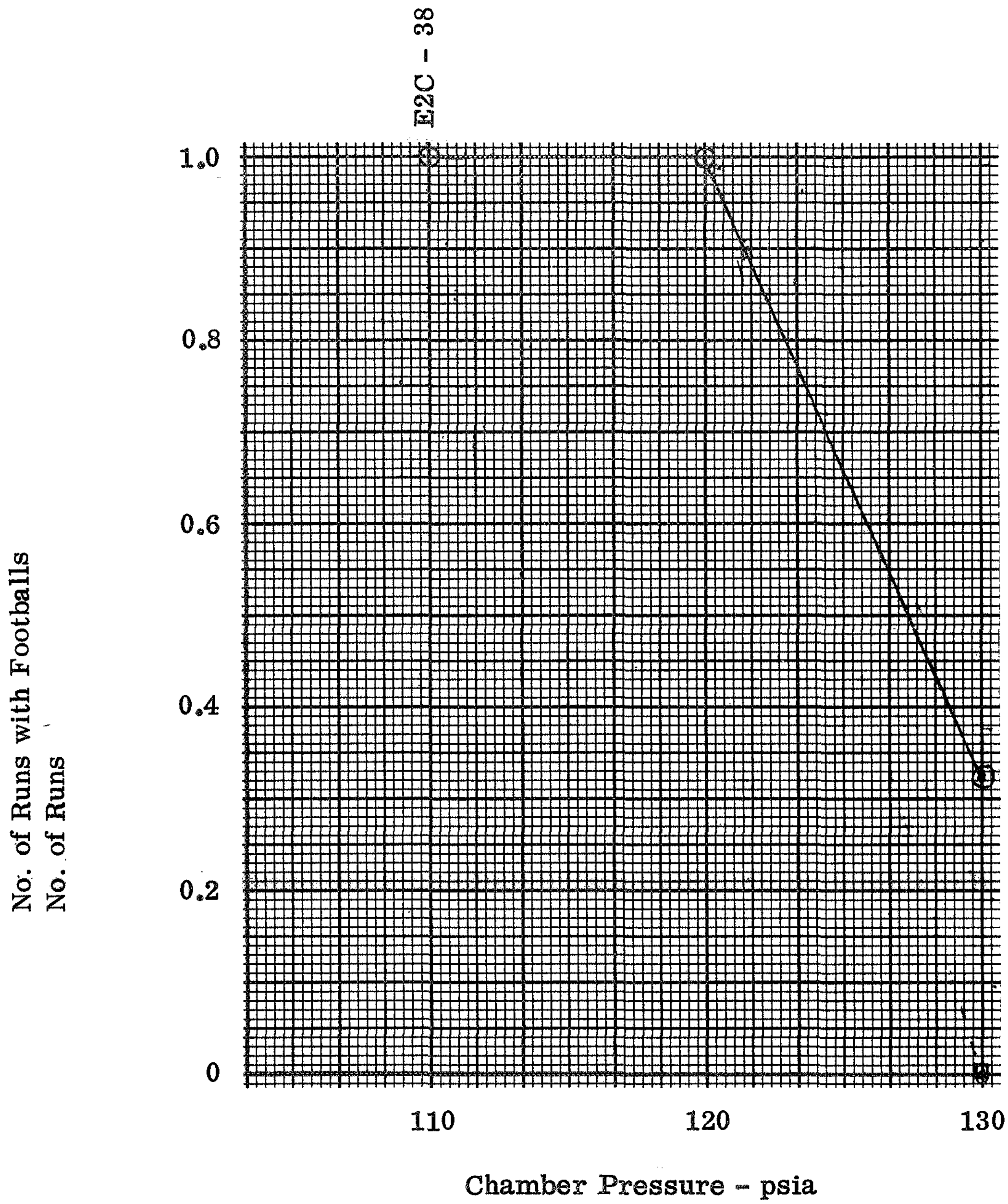


Figure 9c. Incidence of Runs with Footballs versus Chamber pressure

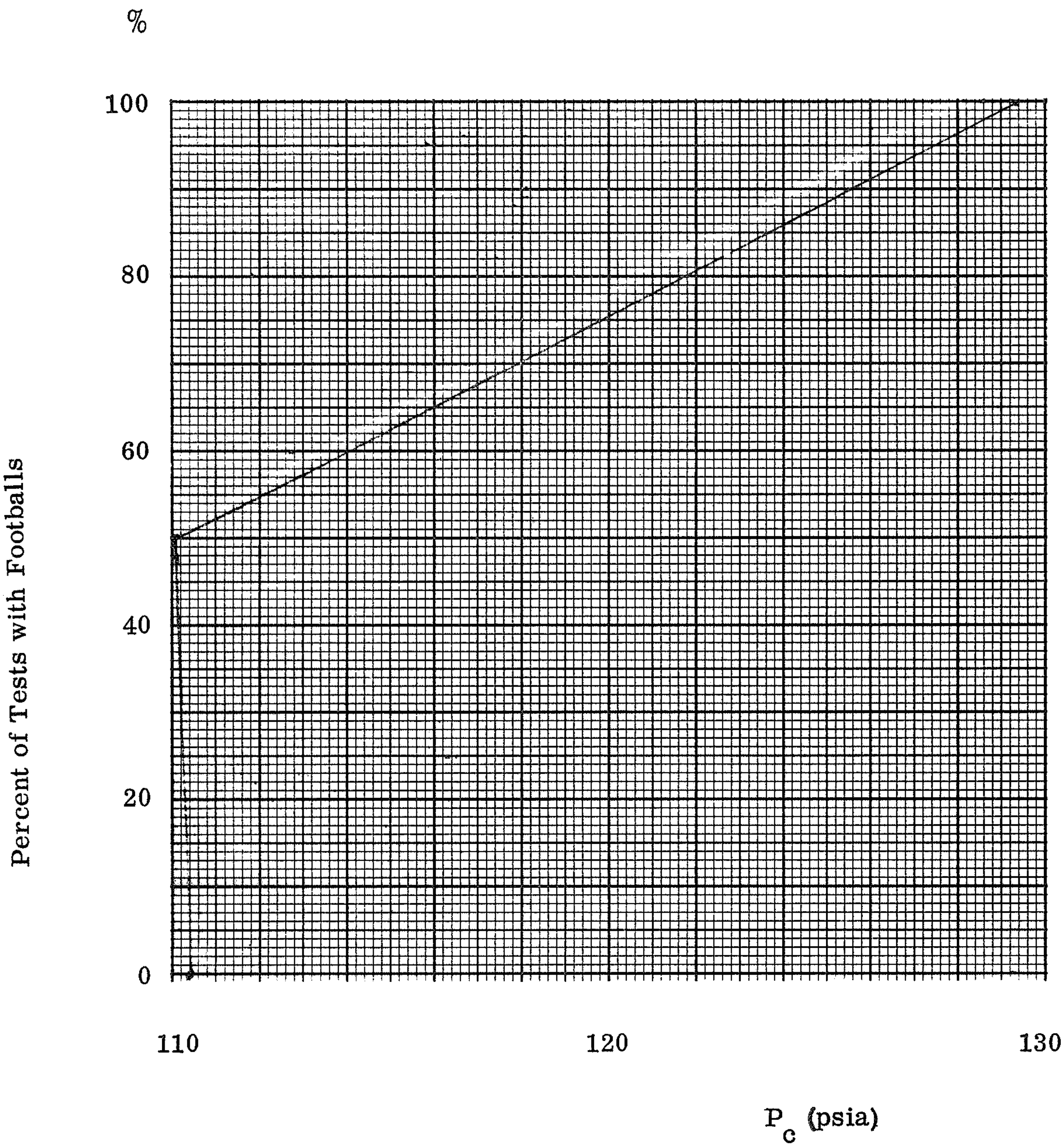


Figure 9d. Incidence of Runs with Footballs versus Chamber Pressure

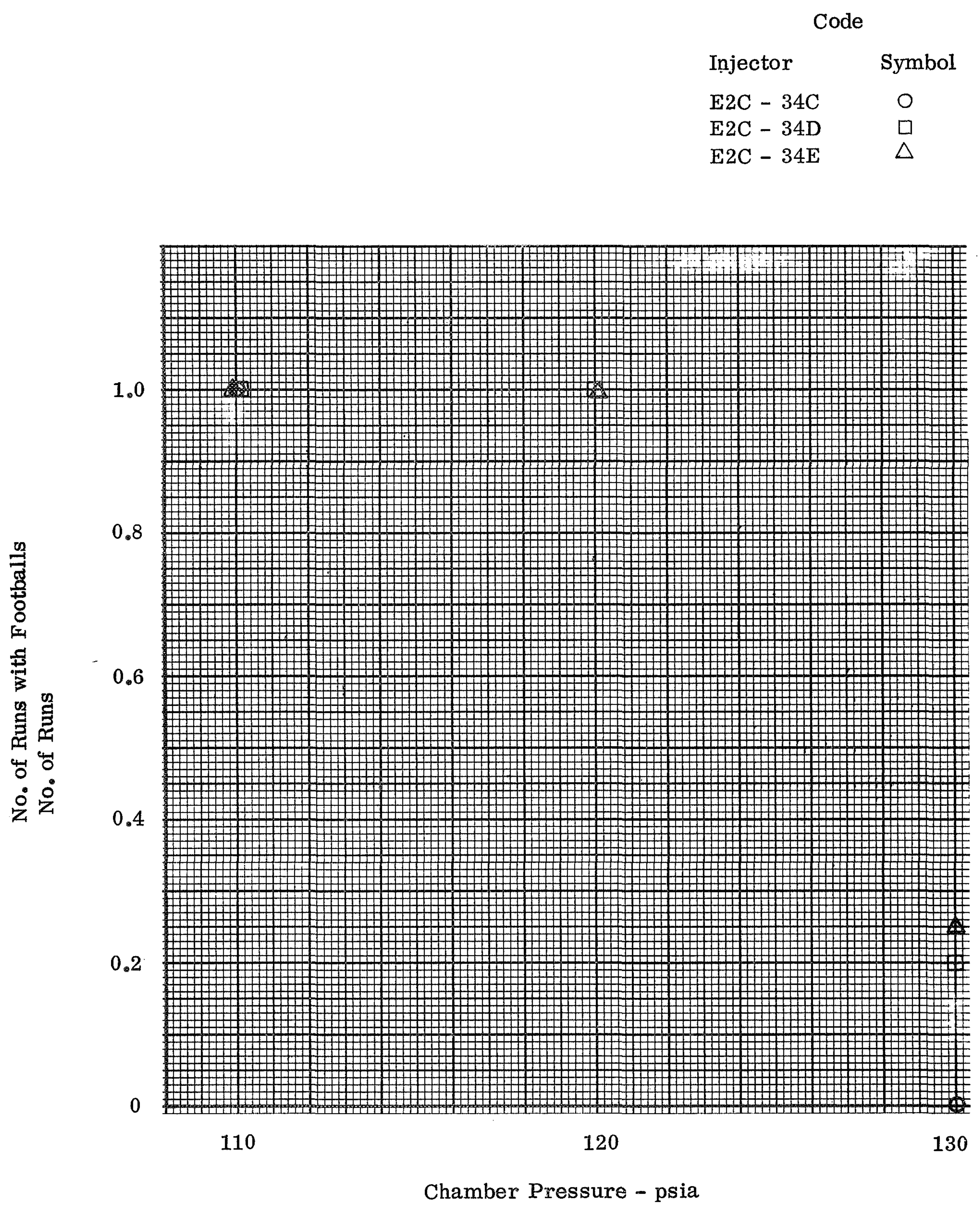


Figure 9e. Incidence of Runs with Footballs
versus Chamber Pressure

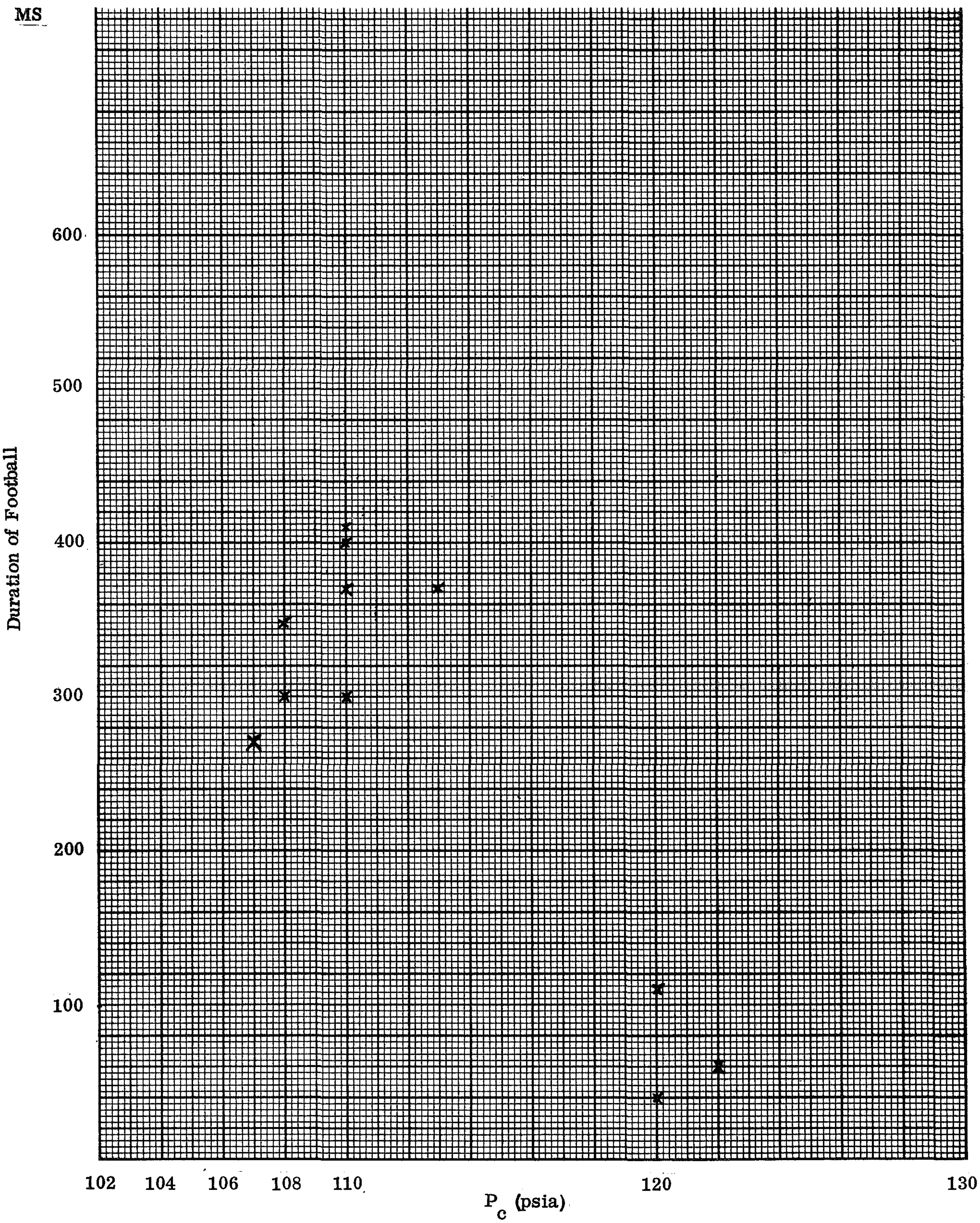

MS
600
500
400
300
200
100
Duration of Football
102
104
106
108
110
120
130
P_c (psia)

Figure 10a

EIE - 1B

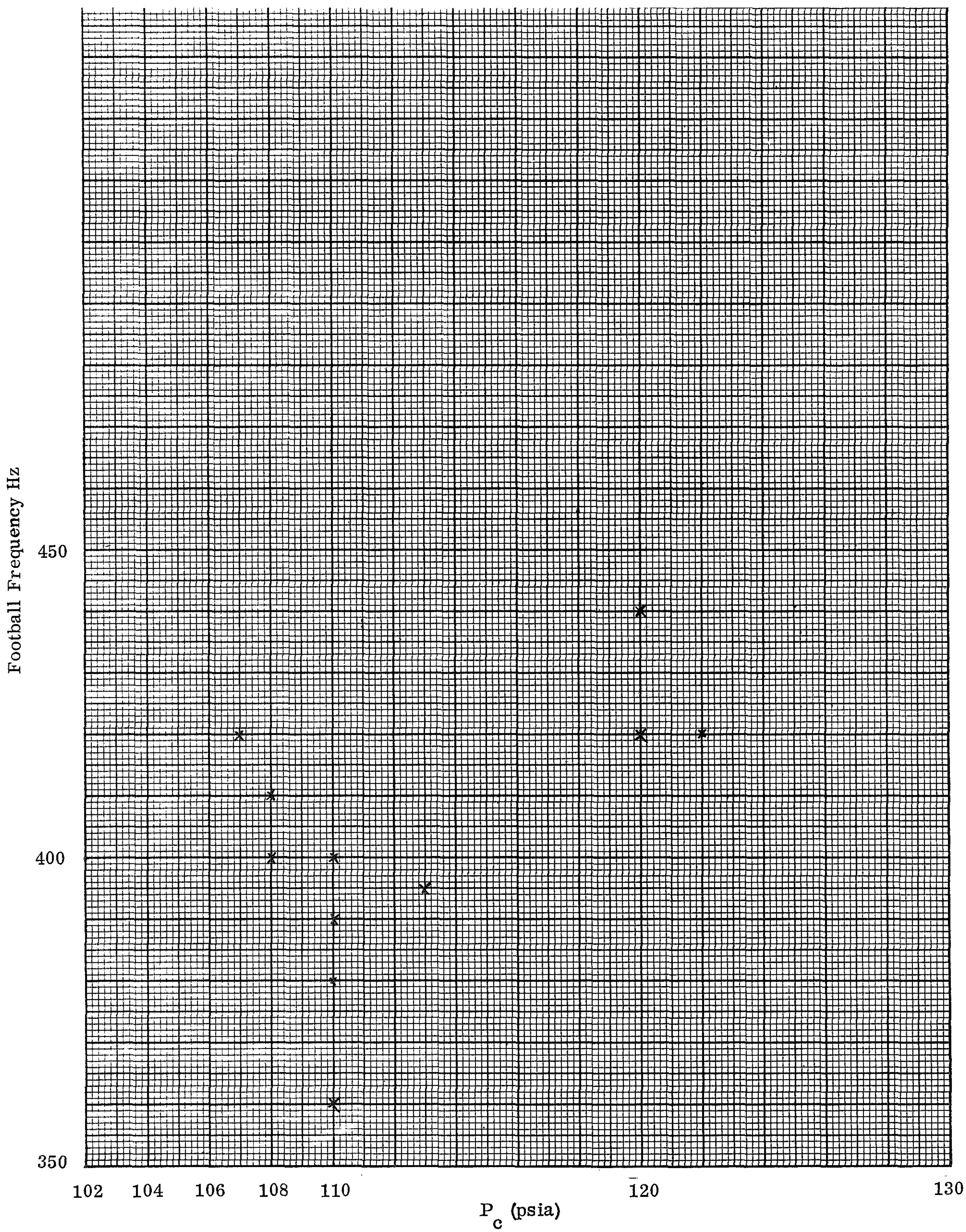
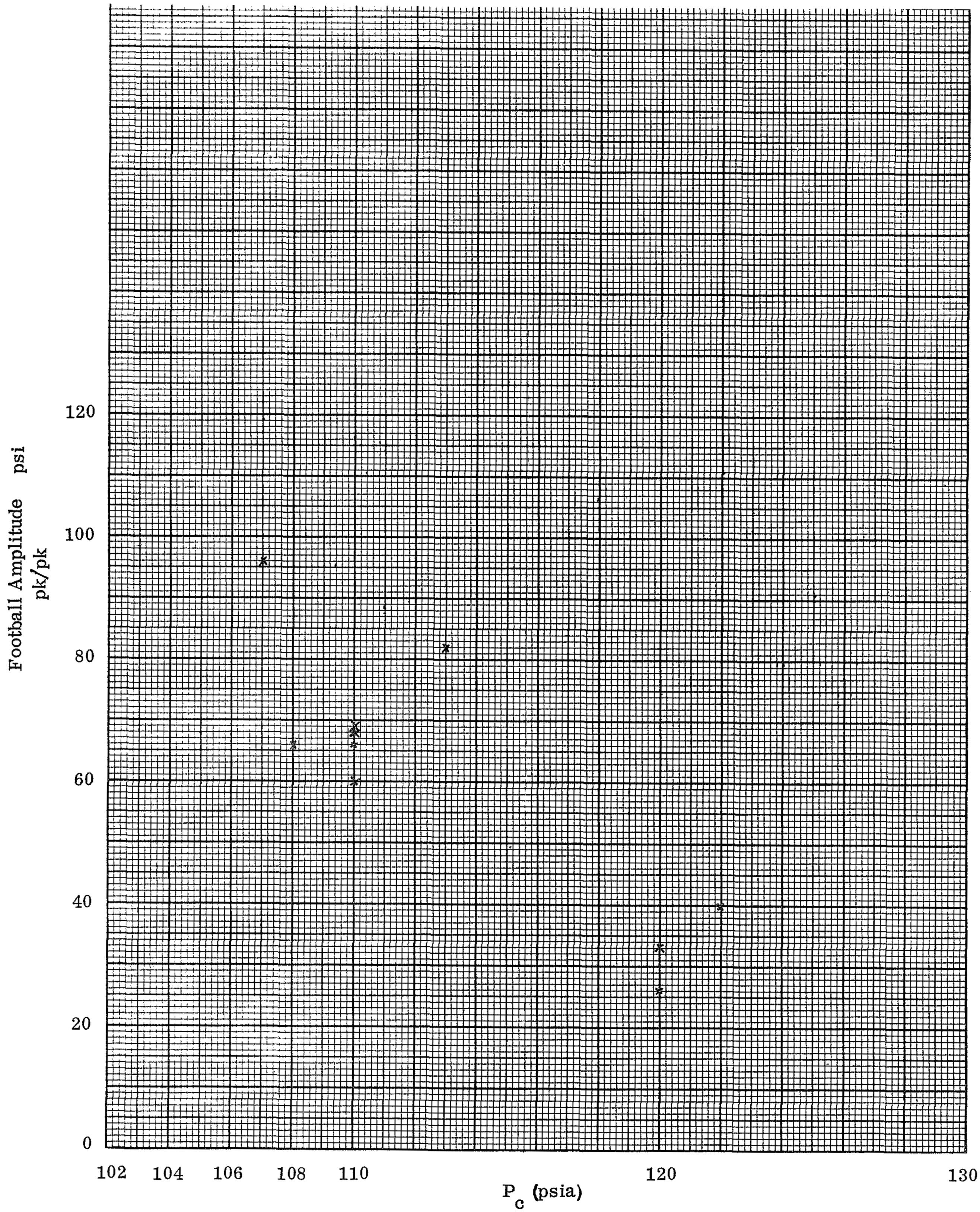


Figure 10b



Football Amplitude psi
pk/pk
120
100
80
60
40
20
0
102
104
106
108
110
120
130
P c (psia)

Figure 10c

EIE - 1B

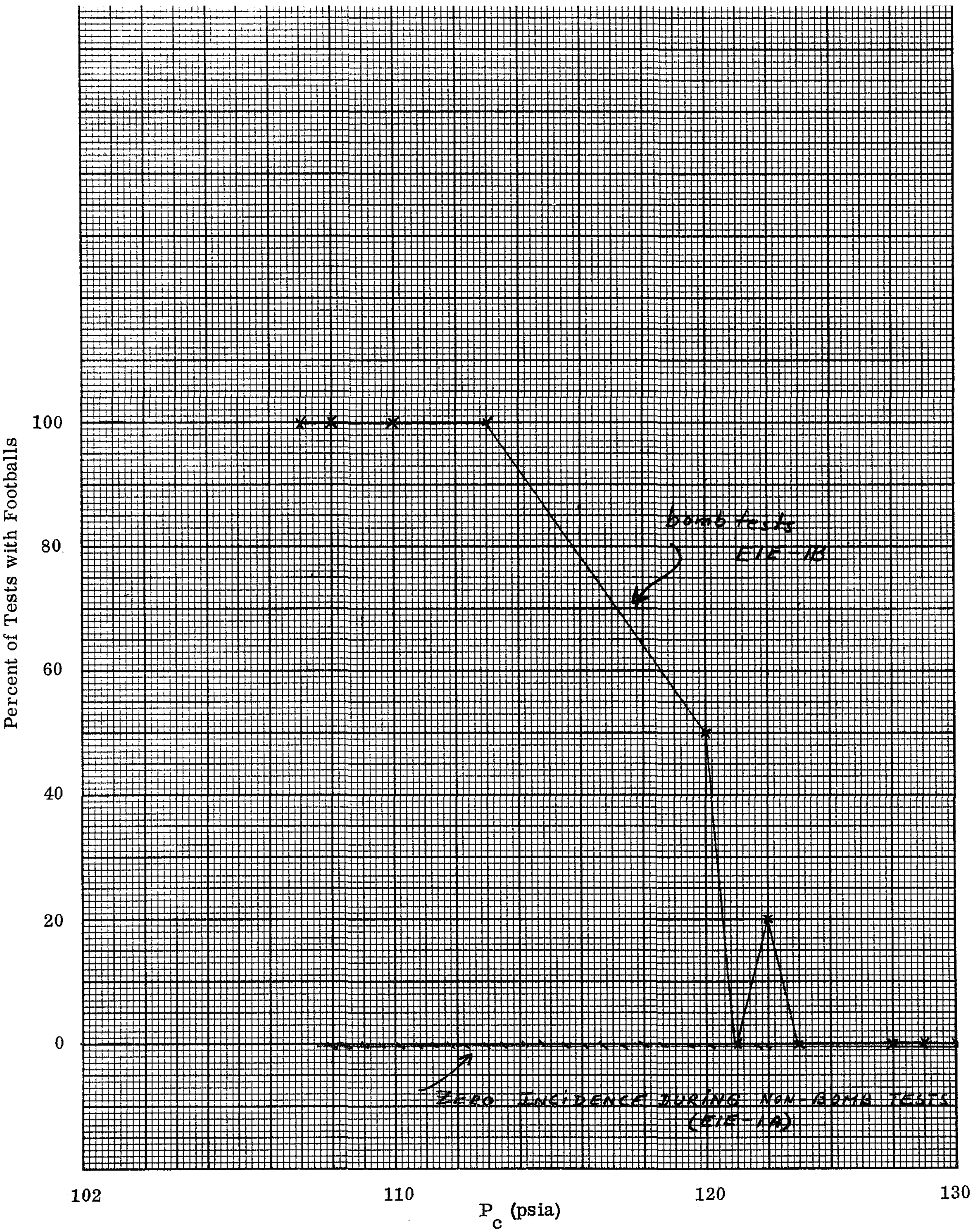


Figure 10d

pressure drop alleviates, although not completely eliminates "footballs." It also demonstrates very dramatically the fact that the incidence rate is markedly higher during high rate of testing, such as occurs during bomb tests.

Having analyzed the characteristics of the "footballs," the question of whether "footballs" affect high frequency instability can be evaluated. Two basic considerations are evident:

1. Do "footballs" initiate a spontaneous transition into high frequency instability?

2. Do "footballs" change the nature and effect of a generated large amplitude disturbance (bomb or spike) to promote high frequency instability?

Same reasoning held for not bomb testing

In the hundreds of tests in which "footballs" were encountered, not one single instance has ever been observed where a "football" type low frequency oscillation spontaneously incited high frequency instability. This is evidence, based on a large sample size, that "football" oscillations do not trigger steady state instability.

In the course of the bomb testing with E2C injectors, 45 bombs were detonated when a "football" type oscillation was still in progress. These tests are enumerated in Figure 11. Only one instability was ever encountered in this array of tests. This was with a 0.455" high circular ring with a 0.050 inch radius of curvature (Test 3DE-1278). Testing with these contoured rings was conducted to assess their stability characteristics. The results of the evaluation, based on 5 instabilities maintained with contoured configurations, were that such contouring degrades the dyanmic stability characteristics.

Inj. S/N	Configuration	Test Cell	Test No.	P_c Level	Test Duration	Remarks (State of Football after Detonation)
E2C-34C	0.455 High	3DE	1278	110	3	Unstable
	Ring - 0.368		1283	111	3.1	Terminated
	Wide - 0.05 in.		1284	111	3.1	Continuous
	Radius		1285	111	2.3	
			1290	111	2.6	
E2C-34D	0.50 High		1295	112	1.1	
	Ring - 0.095		1296	111	1.0	
	Wide (Shaped)		1297	112	1.0	Continuous
	0.02 Radii		1298	111	1.1	Terminated
			1315	112	1.0	Continuous
			1317	113	1.0	
			1318	112	1.0	
E2C-34E	As Above		1324	112	1.0	
	But S.S. Ring	3DE	1327	110	1.0	
E2C-39	Fuel Orifice	2BE	2601	115	1	
	Blocked	2BE	2602	117	1	
	No Ring					
E2C-38	No Ring	3DE	887	105	1	
	or Resonator	3DE	888	105	1	
		3DE	890	105	1	
E2C-38K	0.05 High	2BE	2430	110	3	
	Ring 0.368	2BE	2435	110	1	
E2C-47D	No Ring	3DE	1180	120	3	
	Resonator Open	3DE	1181	120	3	
E2C-47E	No Ring	2BE	2463	120	3	Continuous
	Resonator Open	2BE	2464	120	3	Terminated
E2C-47F	Resonator	2BE	2482	110	1	Continuous
	No Ring					
E2C-47G	0.50 High	2BE	2486	110	1	
	Ring - 0.368		2487	120	3	
	Wide		2494	110	1	
	Sharp Edge		2495	110	1	
	Resonator Open		2496	110	1	
			2506	120	3	
			2507	120	3	
E2C-47H	As Above		2523	110	1	
	Resonator		2524	110	1	
	Closed	2BE	2525	110	1	
			2532	120	3	Continuous

Figure 11. Bomb during Football (E2C Injectors)

Inj. S/N	Configuration	Test Cell	Test No.	P_c Level	Test Duration	Remarks (State of Football after Detonation)
E2C-47I	As "H" But Gap Between Ring and Y Baffle	2BE	2547	110	1	Continuous
			2548	110	1	
		2BE	2549	110	1	
E2C-47J	0.40 High Ring 0.368 Wide	3DE	1244	110	1	
E2C-48B	0.405 High Ring 0.368 Wide 0.02 Radii		1261	110	1	
			1263	110	1	
			1264	110	1	
		3DE	1267	110	3	Continuous

Figure 11. Bomb during Football (E2C Injectors) (Cont)

In order to establish whether the presence of the "football" might have had any influence on the instability, the Kistler P_c analog was digitized. A 5 millisecond period immediately prior to the bomb detonation was then played through a filter corresponding to the "football" frequency in order to establish the amplitude output; then a 5 millisecond period slice immediately after the principal bomb overpressure spike was analyzed for the same "football" frequency component. The ratio of the respective outputs from the two time slices indicated that the "football"-type oscillation progresses through the detonation and incipient instability period relatively unchanged. There is a slight increase in magnitude; however this is consistent with observations obtained in the stable tests. This conclusion seems also consistent with the observation that in all 45 bomb tests during a "football" except for 3 listed in Figure 11, the "football" oscillations continued on relatively unchanged once the bomb detonation overpressure was decayed.

In addition to the 45 bomb tests during a "football," 17 tests were recorded where pressure spikes equal in magnitude to those generated by a bomb were encountered during testing. The reasons for these spikes were traceable in all cases to hardware or test anomalies which have been reported in a separate paper; however all of these disturbances occurred during a "football." Dynamic stability was maintained in all instances. The test numbers are summarized in Figure 12.

CONCLUSION

A. Based on the data presented, it is concluded that "footballs" are discrete, short duration ($\sim$ 200 milliseconds) disturbances caused by two-phase flow inhomogeneities in the fuel systems. These can be caused by gas liberation during start transients and/or gas pockets located within the feed system.

B. These short-duration oscillations have no adverse effect on engine operation and high frequency instability.

INJ S/N	CONFIGURATION	TEST NO.	TIME OF DISTURBANCE (SEC)	MAX g P-P	KISTLER OVERPRESS. T_CP_C-1 psia	KISTLER OVERPRESS. T_CP_C-2 psia
E1C-1D	4.5 IN. RING + ACOUSTIC DAMPERS	1116 3DE	0.510	1350	-	-
E1C-1F	4.5 IN. RING + ACOUSTIC DAMPER PARTIALLY PLUGGED	1156 3DE	0.361	3450	382	334
E1C-1G	4.5 IN. RING + ACOUSTIC DAMPER PARTIALLY PLUGGED	772 3DW	0.5[illegible]1	1450	-	-
E1C-1H	4.5 IN. RING + ACOUSTIC DAMPER PARTIALLY PLUGGED	422 2DW	0.306	>2000	233	220
E1C-1H	4.5 IN. RING + ACOUSTIC DAMPER PARTIALLY PLUGGED	423 2DW	0.307	>2000	269	268
E2C-38B	SINGLE CAVITY ACOUSTIC DAMPER	261 2DW	0.338	1900	150	LOST
E2C-38K	THREE CAVITY ACOUSTIC DAMPER + 4.5 IN. RING	393 2DW	0.421	4350	276	249
E2C-38K	THREE CAVITY ACOUSTIC DAMPER + 4.5 IN.RING	396 2DW	0.457	1250	137	200
E2C-38K	THREE CAVITY ACOUSTIC DAMPER + 4.5 IN. RING	399 2DW	0.459	>1400	150	118
E2C-38K	THREE CAVITY ACOUSTIC DAMPER + 4.5 IN. RING	2457 2BE	0.398	4550	LOST	229
E2C38N	THREE CAVITY ACOUSTIC DAMPER + 4.5 IN. RING	498 2DW	0.411	2850	285	237
E2B-44B	THREE CAVITY ACOUSTIC DAMPER	2409 2BE	0.285	>3450	267	246
E2B-44B	THREE CAVITY ACOUSTIC DAMPER	2423 2BE	0.284	1900	144	188
E2C-47G	4.5 IN. RING + THREE CAVITY ACOUSTIC DAMPER	2489 2BE	0.348	1450	-	-
E2C-47G	4.5 IN. RING + THREE CAVITY ACOUSTIC DAMPER	2503 2BE	0.714	3500	253	271
E2C-47G	4.5 IN. RING + THREE CAVITY ACOUSTIC DAMPER	2503 2BE	0.733	4650	253	326
E2C-47G	4.5 IN. RING + THREE CAVITY ACOUSTIC DAMPER	2505 2BE	0.849	>4950	386	310
E2C-47H	4.5 IN. RING + ALL ACOUSTIC PORTS PLUGGED	2526 2BE	0.656	1825	LOST	292

Figure 12. Automatic Shutdown Caused by Pressure Spikes during Start